

US008978373B2

(12) **United States Patent**
Opdenbosch et al.

(10) **Patent No.:** **US 8,978,373 B2**
(45) **Date of Patent:** **Mar. 17, 2015**

(54) **METERLESS HYDRAULIC SYSTEM HAVING
FLOW SHARING AND COMBINING
FUNCTIONALITY**

2211/7058; E02F 9/2285; E02F 9/2289;
E02F 9/2292; E02F 9/2228; E02F 9/2296
USPC 60/420, 421, 422, 484, 486
See application file for complete search history.

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(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 670 days.

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(22) Filed: **Oct. 21, 2011**

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(65) **Prior Publication Data**
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(51) **Int. Cl.**
F15B 11/17 (2006.01)
E02F 9/22 (2006.01)

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(52) **U.S. Cl.**
CPC **F15B 11/17** (2013.01); **E02F 9/2242**
(2013.01); **E02F 9/2289** (2013.01); **E02F**
9/2292 (2013.01); **E02F 9/2296** (2013.01);
F15B 2211/20546 (2013.01); **F15B 2211/20561**
(2013.01); **F15B 2211/20569** (2013.01); **F15B**
2211/20576 (2013.01); **F15B 2211/255**
(2013.01); **F15B 2211/265** (2013.01); **F15B**
2211/27 (2013.01); **F15B 2211/30525**
(2013.01); **F15B 2211/30575** (2013.01);
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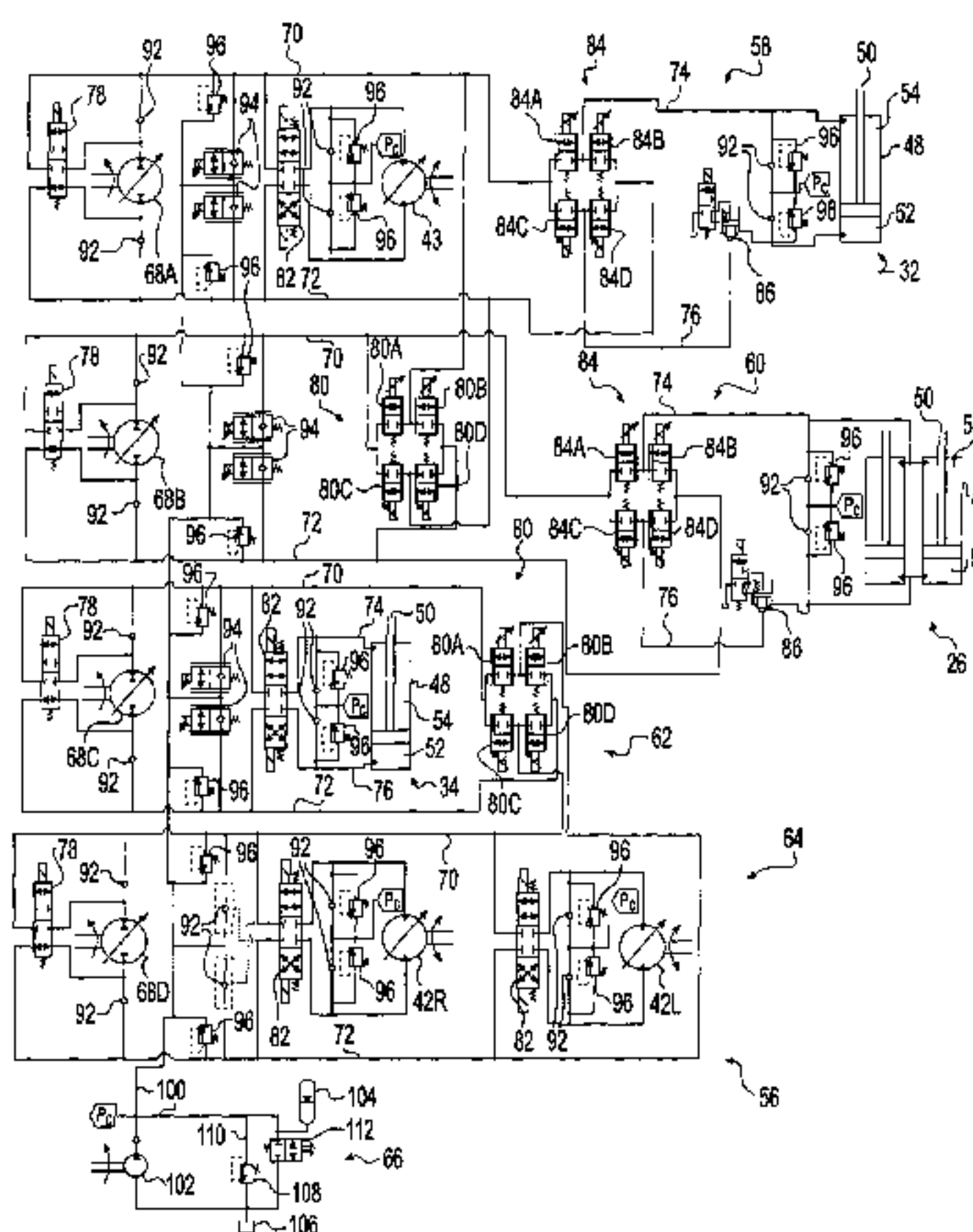
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ABSTRACT

A hydraulic system includes a variable-displacement first pump, a variable-displacement second pump, and a first actuator selectively connected either to the first pump in a closed loop manner and not the second pump, or to the first and second pumps in a closed loop manner. The hydraulic system also includes a second actuator selectively connected either to the second pump in a closed loop manner and not the first pump, or to the first and second pumps in a closed loop manner. The hydraulic system further includes a variable-displacement rotary actuator selectively connected either to the first pump in a closed loop manner and not the second pump, or to the first and second pumps in a closed loop manner.

(58) **Field of Classification Search**
CPC **F15B 11/17**; **F15B 2211/20546**; **F15B**
2211/20561; **F15B 2211/265**; **F15B**
2211/3111; **F15B 2211/3116**; **F15B**
2211/3144; **F15B 2211/7053**; **F15B**

20 Claims, 2 Drawing Sheets



(52) U.S. Cl.

CPC .. *F15B 2211/30595* (2013.01); *F15B 2211/35*
(2013.01); *F15B 2211/613* (2013.01); *F15B*
2211/7142 (2013.01); *F15B 2211/763*
(2013.01); *F15B 2211/78* (2013.01)
USPC 60/421; 60/422

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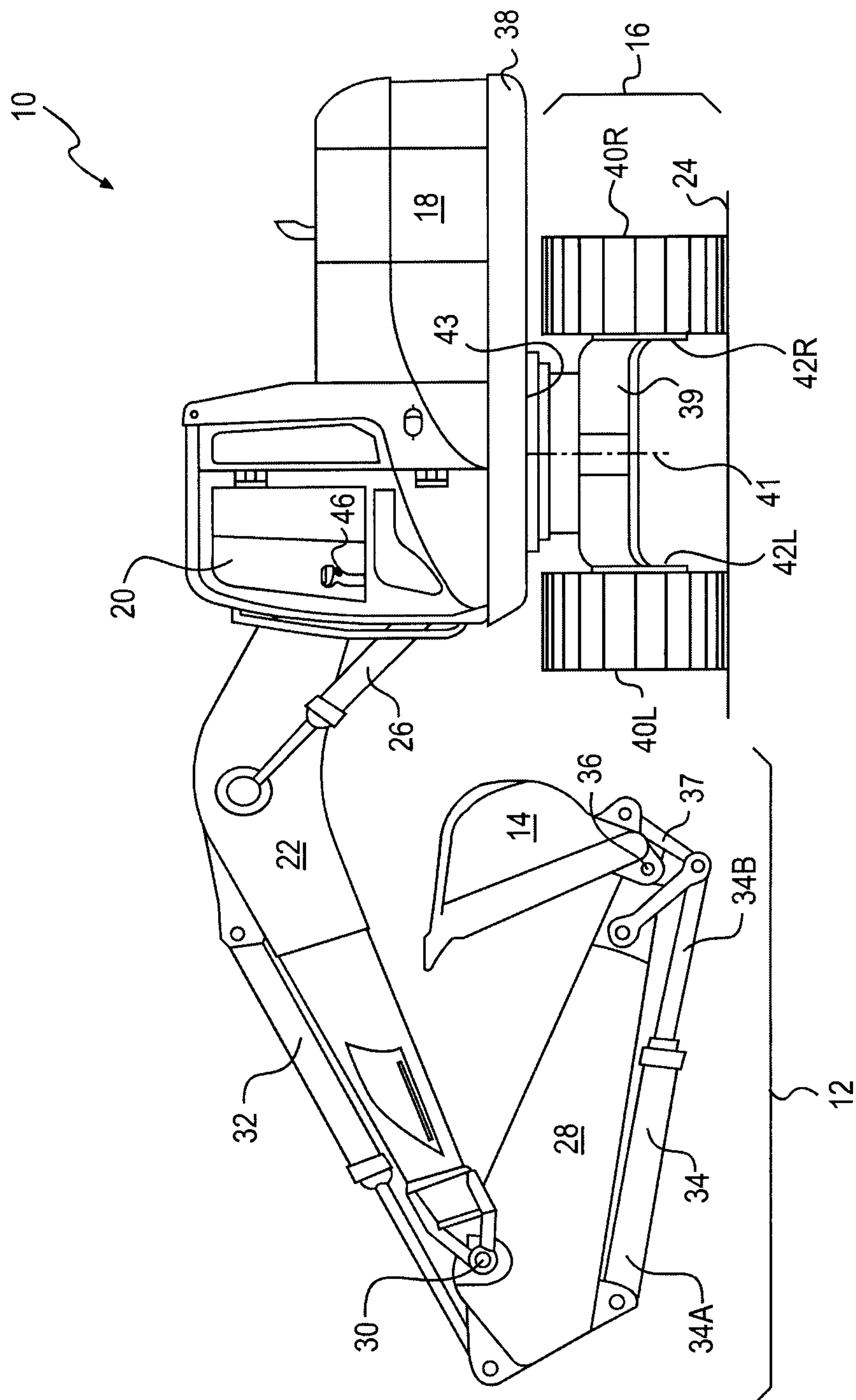


FIG. 1

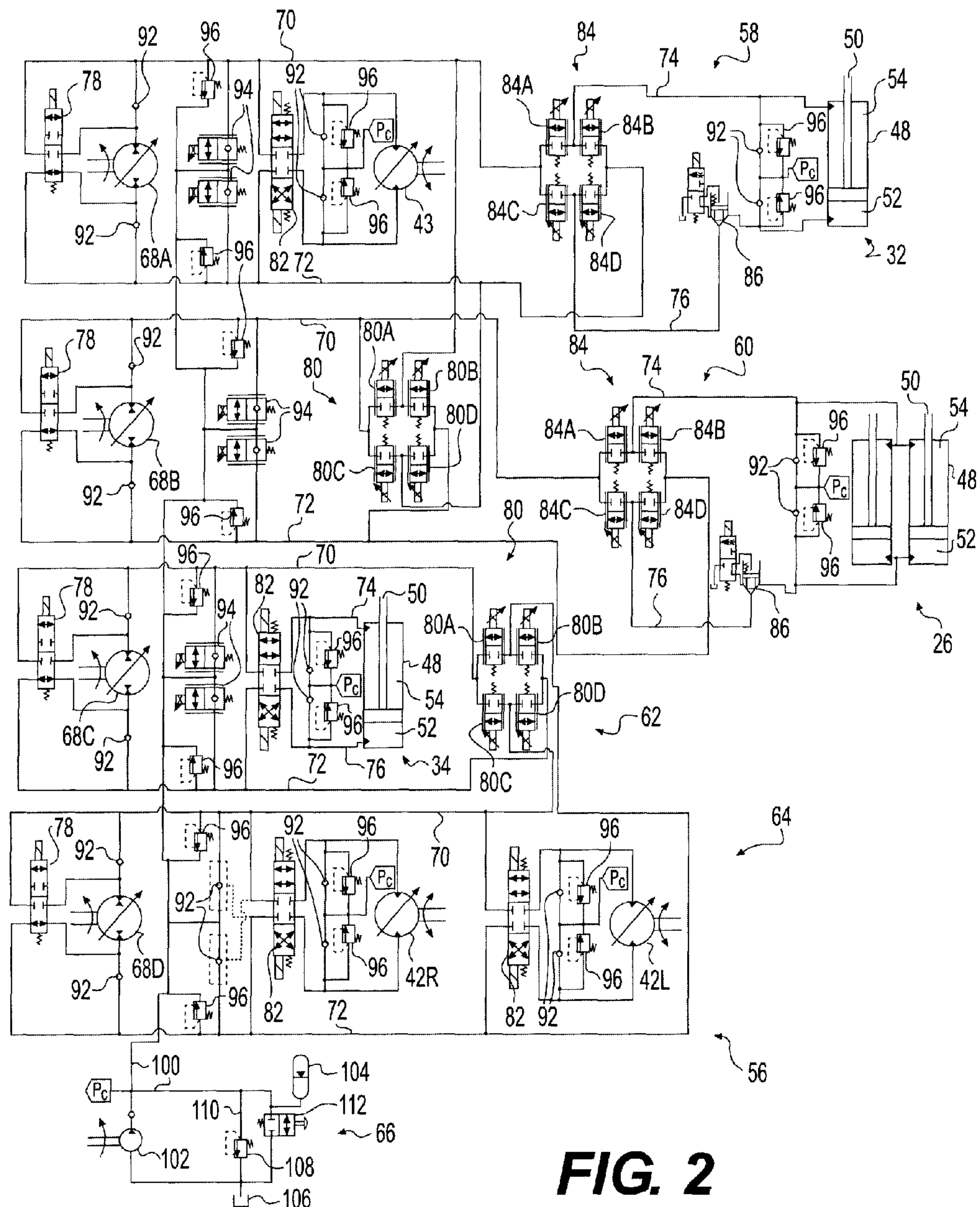


FIG. 2

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METERLESS HYDRAULIC SYSTEM HAVING FLOW SHARING AND COMBINING FUNCTIONALITY

TECHNICAL FIELD

The present disclosure relates generally to a hydraulic system and, more particularly, to a meterless hydraulic system having flow sharing and combining functionality.

BACKGROUND

A conventional hydraulic system includes a pump that draws low-pressure fluid from a tank, pressurizes the fluid, and makes the pressurized fluid available to multiple different actuators for use in moving the actuators. In this arrangement, a speed of each actuator can be independently controlled by selectively throttling (i.e., restricting) a flow of the pressurized fluid from the pump into each actuator. For example, to move a particular actuator at a high speed, the flow of fluid from the pump into the actuator is restricted by only a small amount. In contrast, to move the same or another actuator at a low speed, the restriction placed on the flow of fluid is increased. Although adequate for many applications, the use of fluid restriction to control actuator speed can result in flow losses that reduce an overall efficiency of a hydraulic system.

An alternative type of hydraulic system is known as a meterless hydraulic system. A meterless hydraulic system generally includes a pump connected in closed-loop fashion to a single actuator or to a pair of actuators operating in tandem. During operation, the pump draws fluid from one chamber of the actuator(s) and discharges pressurized fluid to an opposing chamber of the same actuator(s). To move the actuator(s) at a higher speed, the pump discharges fluid at a faster rate. To move the actuator with a lower speed, the pump discharges the fluid at a slower rate. A meterless hydraulic system is generally more efficient than a conventional hydraulic system because the speed of the actuator(s) is controlled through pump operation as opposed to fluid restriction. That is, the pump is controlled to only discharge as much fluid as is necessary to move the actuator(s) at a desired speed, and no throttling of a fluid flow is required.

An exemplary meterless hydraulic system is disclosed in U.S. Pat. No. 4,369,625 of Izumi et al., which published on Jan. 25, 1983 (the '625 patent). In the '625 patent, a multi-actuator meterless-type hydraulic system is described that has flow combining functionality. The hydraulic system includes a swing circuit, a boom circuit, a stick circuit, a bucket circuit, a left travel circuit, and a right travel circuit. Each of the swing, boom, stick, and bucket circuits have a pump connected to a specialized actuator in a closed-loop manner. In addition, a first combining valve is connected between the swing and stick circuits, a second combining valve is connected between the stick and boom circuits, and a third combining valve is connected between the bucket and boom circuits. The left and right travel circuits are connected in parallel to the pumps of the bucket and boom circuits, respectively. In this configuration, any one actuator can receive pressurized fluid from more than one pump such that its speed is limited by the capacity of a single pump.

Although an improvement over existing meterless hydraulic systems, the meterless hydraulic system of the '625 patent described above may still be less than optimal. In particular, operation of connected circuits of the system may only be sequentially performed. In addition, the speeds and forces of the various actuators may be difficult to control.

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The hydraulic system of the present disclosure is directed toward solving one or more of the problems set forth above and/or other problems of the prior art.

SUMMARY

In one aspect, the present disclosure is directed to a hydraulic system including a variable-displacement first pump, a variable-displacement second pump, and a first actuator selectively connected either to the first pump in a closed loop manner and not the second pump, or to the first and second pumps in a closed loop manner. The hydraulic system also includes a second actuator selectively connected either to the second pump in a closed loop manner and not the first pump, or to the first and second pumps in a closed loop manner. The hydraulic system further includes a variable-displacement rotary actuator selectively connected either to the first pump in a closed loop manner and not the second pump, or to the first and second pumps in a closed loop manner.

In another aspect, the present disclosure is directed to a hydraulic system including a variable-displacement first pump, a variable-displacement second pump, a first actuator connected to the first pump in a closed loop manner, a second actuator selectively connected to the second pump in a closed loop manner, and a variable-displacement rotary actuator selectively connected to the first pump in a closed loop manner. The hydraulic system also includes a combiner valve arrangement configured to selectively connect and disconnect the second pump from the first actuator and the rotary actuator, and selectively connect and disconnect the first pump from the second actuator. The hydraulic system further includes at least one switching valve fluidly connected to at least one of the first actuator, the second actuator, or the rotary actuator. The at least one switching valve is configured to control an amount of fluid passing through a first actuator passage and a second actuator passage connected to the at least one of the first actuator, the second actuator, or the rotary actuator.

In another aspect, the present disclosure is directed to a method of operating a hydraulic system. The method includes pressurizing fluid with a first variable-displacement pump and pressurizing fluid with a second variable-displacement pump. The first and second pumps are capable of simultaneously supplying pressurized fluid to at least three actuators. The at least three actuators include a variable-displacement rotary actuator, a linear actuator, and a third actuator. The method also includes selectively controlling whether to direct fluid pressurized by the first pump and the second pump to only one of the at least three actuators, to only two of the at least three actuators simultaneously, or to three of the at least three actuators simultaneously. The method further includes returning the pressurized fluid to the first and second pumps in a closed-loop manner, adjusting displacement of the rotary actuator to control torque output of the rotary actuator, and metering the flow passing between the first and second pumps and the linear actuator to control movement of the linear actuator.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a pictorial illustration of an exemplary disclosed machine; and

FIG. 2 is a schematic illustration of an exemplary disclosed hydraulic system that may be used in conjunction with the machine of FIG. 1.

DETAILED DESCRIPTION

FIG. 1 illustrates an exemplary machine 10 having multiple systems and components that cooperate to accomplish a

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task. Machine **10** may embody a fixed or mobile machine that performs some type of operation associated with an industry such as mining, construction, farming, transportation, or another industry known in the art. For example, machine **10** may be an earth moving machine such as an excavator (shown in FIG. 1), a dozer, a loader, a backhoe, a motor grader, a dump truck, or any other earth moving machine. Machine **10** may include an implement system **12** configured to move a work tool **14**, a drive system **16** for propelling machine **10**, a power source **18** that provides power to implement system **12** and drive system **16**, and an operator station **20** situated for manual control of implement system **12**, drive system **16**, and/or power source **18**.

Implement system **12** may include a linkage structure acted on by fluid actuators to move work tool **14**. Specifically, implement system **12** may include a boom **22** that is vertically pivotal about a horizontal axis (not shown) relative to a work surface **24** by a pair of adjacent, double-acting, hydraulic cylinders **26** (only one shown in FIG. 1). Implement system **12** may also include a stick **28** that is vertically pivotal about a horizontal axis **30** by a single, double-acting, hydraulic cylinder **32**. Implement system **12** may further include a single, double-acting, hydraulic cylinder **34** that is operatively connected between stick **28** and work tool **14** to pivot work tool **14** vertically about a horizontal pivot axis **36**. In the disclosed embodiment, hydraulic cylinder **34** is connected at a head-end **34A** to a portion of stick **28** and at an opposing rod-end **34B** to work tool **14** by way of a power link **37**. Boom **22** may be pivotally connected to a body **38** of machine **10**. Body **38** may be pivotally connected to an undercarriage **39** and movable about a vertical axis **41** by a hydraulic swing motor **43**. Stick **28** may pivotally connect boom **22** to work tool **14** by way of axis **30** and **36**.

Numerous different work tools **14** may be attachable to a single machine **10** and operator controllable. Work tool **14** may include any device used to perform a particular task such as, for example, a bucket, a fork arrangement, a blade, a shovel, a ripper, a dump bed, a broom, a snow blower, a propelling device, a cutting device, a grasping device, or any other task-performing device known in the art. Although connected in the embodiment of FIG. 1 to pivot in the vertical direction relative to body **38** of machine **10** and to swing in the horizontal direction, work tool **14** may alternatively or additionally rotate, slide, open and close, or move in any other manner known in the art.

Drive system **16** may include one or more traction devices powered to propel machine **10**. In the disclosed example, drive system **16** includes a left track **40L** located on one side of machine **10**, and a right track **40R** located on an opposing side of machine **10**. Left track **40L** may be driven by a left travel motor **42L**, while right track **40R** may be driven by a right travel motor **42R**. It is contemplated that drive system **16** could alternatively include traction devices other than tracks such as wheels, belts, or other known traction devices. Machine **10** may be steered by generating a speed and/or rotational direction difference between left and right travel motors **42L**, **42R**, while straight travel may be facilitated by generating substantially equal output speeds and rotational directions from left and right travel motors **42L**, **42R**.

Power source **18** may embody an engine such as, for example, a diesel engine, a gasoline engine, a gaseous fuel-powered engine, or any other type of combustion engine known in the art. It is contemplated that power source **18** may alternatively embody a non-combustion source of power such as a fuel cell, a power storage device, or another source known in the art. Power source **18** may produce a mechanical or electrical power output that may then be converted to hydrau-

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lic power for moving hydraulic cylinders **26**, **32**, **34** and left travel, right travel, and swing motors **42L**, **42R**, **43**.

Operator station **20** may include devices that receive input from a machine operator indicative of desired machine maneuvering. Specifically, operator station **20** may include one or more operator interface devices **46**, for example a joystick, a steering wheel, or a pedal, that are located proximate an operator seat (not shown). Operator interface devices **46** may initiate movement of machine **10**, for example travel and/or tool movement, by producing displacement signals that are indicative of desired machine maneuvering. As an operator moves interface device **46**, the operator may affect a corresponding machine movement in a desired direction, with a desired speed, and/or with a desired force.

As shown in FIG. 2, hydraulic cylinders **26**, **32**, **34** may each include a tube **48** and a piston assembly **50** arranged within tube **48** to form a first chamber **52** and an opposing second chamber **54**. In one example, a rod portion of piston assembly **50** may extend through an end of second chamber **54**. As such, second chamber **54** may be considered the rod-end chamber of hydraulic cylinders **26**, **32**, **34**, while first chamber **52** may be considered the head-end chamber.

First and second chambers **52**, **54** may each be selectively supplied with pressurized fluid and drained of the pressurized fluid to cause piston assembly **50** to displace within tube **48**, thereby changing an effective length of hydraulic cylinders **26**, **32**, **34** and moving work tool **14** (referring to FIG. 1). A flow rate of fluid into and out of first and second chambers **52**, **54** may relate to a translational velocity of hydraulic cylinders **26**, **32**, **34**, while a pressure differential between first and second chambers **52**, **54** may relate to a force imparted by hydraulic cylinders **26**, **32**, **34** on the associated linkage structure of implement system **12**.

Swing motor **43**, like hydraulic cylinders **26**, **32**, **34**, may be driven by a fluid pressure differential. Specifically, swing motor **43** may include first and second chambers (not shown) located to either side of a pumping mechanism such as an impeller, plunger, or series of pistons (not shown). When the first chamber is filled with pressurized fluid and the second chamber is drained of fluid, the pumping mechanism may be urged to move or rotate in a first direction. Conversely, when the first chamber is drained of fluid and the second chamber is filled with pressurized fluid, the pumping mechanism may be urged to move or rotate in an opposite direction. The flow rate of fluid into and out of the first and second chambers may determine an output velocity of swing motor **43**, while a pressure differential across the pumping mechanism may determine an output torque. It is contemplated that a displacement of swing motor **43** may be variable in the positive and/or negative direction (e.g., in an over-center configuration or a non-over-center configuration, as shown in FIG. 2), if desired, such that for a given flow rate and/or pressure of supplied fluid, a speed and/or torque output of swing motor **43** may be adjusted.

Similar to swing motor **43**, each of left and right travel motors **42L**, **42R** may be driven by creating a fluid pressure differential. Specifically, each of left and right travel motors **42L**, **42R** may include first and second chambers (not shown) located to either side of a pumping mechanism (not shown). When the first chamber is filled with pressurized fluid and the second chamber is drained of fluid, the pumping mechanism may be urged to move or rotate a corresponding traction device (**40L**, **40R**) in a first direction. Conversely, when the first chamber is drained of the fluid and the second chamber is filled with the pressurized fluid, the respective pumping mechanism may be urged to move or rotate the traction device in an opposite direction. The flow rate of fluid into and out of

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the first and second chambers may determine a velocity of left and right travel motors **42L**, **42R**, while a pressure differential between left and right travel motors **42L**, **42R** may determine a torque. It is contemplated that a displacement of left and right travel motors **42L**, **42R** may be variable in the positive and/or negative direction (e.g., in an over-center configuration or a non-over-center configuration, as shown in FIG. 2), if desired, such that for a given flow rate and/or pressure of supplied fluid, a speed and/or torque output of travel motors **42L**, **42R** may be adjusted.

As illustrated in FIG. 2, machine **10** may include a hydraulic system **56** having a plurality of fluid components that cooperate to move work tool **14** (referring to FIG. 1) and machine **10**. In particular, hydraulic system **56** may include, among other things, a first meterless circuit **58**, a second meterless circuit **60**, a third meterless circuit **62**, a fourth meterless circuit **64**, and a charge circuit **66**. First meterless circuit **58** may be a stick circuit associated with hydraulic cylinder **32** and swing motor **43**. Second meterless circuit **60** may be a boom circuit associated with hydraulic cylinders **26**. Third meterless circuit **62** may be a bucket circuit associated with hydraulic cylinder **34**. Fourth meterless circuit **64** may be a travel circuit associated with right travel motor **42R** and left travel motor **42L**. Charge circuit **66** may be in selective fluid communication with each of first, second, third, and fourth meterless circuits **58**, **60**, **62**, **64**. It is contemplated that additional and/or different configurations of meterless circuits may be included within hydraulic system **56** such as, for example, an independent circuit associated with each separate actuator (e.g., hydraulic cylinders **32**, **34**, **26**, left travel motor **42L**, right travel motor **42R**, and/or swing motor **43**), if desired. Also, as an alternative, hydraulic cylinders **32** and **34** may be interchanged such that first meterless circuit **58** may be a bucket circuit associated with hydraulic cylinder **34** and swing motor **43** and third meterless circuit **62** may be a stick circuit associated with hydraulic cylinder **32**.

In the disclosed embodiment, each of meterless circuits **58**, **60**, **62**, **64** may include a plurality of interconnecting and cooperating fluid components that facilitate the use and control of the associated actuators. For example, each meterless circuit **58**, **60**, **62**, **64** may include a respective pump **68A-68D** fluidly connected to its associated rotary and/or linear actuators in parallel via a closed-loop formed by upper-side and lower-side passages. The terms “upper” and “lower” are used herein to refer to positions of the components relative to each other in FIG. 2 for ease of explanation, but the components are not limited to these relative positions in practice.

Specifically, each pump **68A**, **68D** that is connected to a rotary actuator (e.g., to left-travel motor **42L**, right travel motor **42R**, or swing motor **43**) may be connected to the rotary actuator via a first pump passage **70** and a second pump passage **72**. To cause the rotary actuator to rotate in a first direction, first pump passage **70** may be filled with fluid pressurized by the pump (e.g., pump **68A**), while second pump passage **72** may be filled with fluid exiting the rotary actuator. To reverse direction of the rotary actuator, second pump passage **72** may be filled with fluid pressurized by the pump (e.g., pump **68A**), while first pump passage **70** may be filled with fluid exiting the rotary actuator.

In addition, each pump **68A-68C** that is connected to a linear actuator (e.g., to hydraulic cylinders **26**, **32**, or **34**) may be connected to the linear actuator via first and second pump passages **70**, **72**, a rod-end passage **74**, and a head-end passage **76**. During an extending operation of a particular linear actuator, head-end passage **76** may be filled with fluid pressurized by one or more pumps **68A-68C**, while rod-end passage **74** may be filled with fluid returned from the linear

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actuator. In contrast, during a retracting operation, rod-end passage **74** may be filled with fluid pressurized by one or more pumps **68A-68C**, while head-end passage **76** may be filled with fluid returned from the linear actuator.

Each pump **68A-68D** may have variable displacement and be controlled to draw fluid from its associated actuators and discharge the fluid at a specified elevated pressure back to the actuators in two different directions. That is, each pump **68A-68D** may include a stroke-adjusting mechanism, for example a swashplate, a position of which is hydro-mechanically or electro-hydraulically adjusted based on, among other things, a desired speed of the actuators to thereby vary an output (e.g., a discharge rate) of pumps **68A-68D**. The displacement of each pump **68A-68D** may be adjusted from a zero displacement position at which substantially no fluid is discharged from the respective pump **68A-68D**, to a maximum displacement position in a first direction at which fluid is discharged from the respective pump **68A-68D** at a maximum rate into first pump passage **70**. Likewise, the displacement of each pump **68A-68D** may be adjusted from the zero displacement position to a maximum displacement position in a second direction at which fluid is discharged from the respective pump **68A-68D** at a maximum rate into second pump passage **72**. Each pump **68A-68D** may be drivably connected to power source **18** of machine **10** by, for example, a countershaft, a belt, or in another suitable manner. Alternatively, each pump **68A-68D** may be indirectly connected to power source **18** via a torque converter, a gear box, an electrical circuit, or in any other manner known in the art. It is contemplated that pumps **68A-68D** of different circuits may be connected to power source **18** in tandem (e.g., via the same shaft) or in parallel (via a gear train), as desired.

As shown in FIG. 2, pumps **68A-68D** may be over-center pumps or rotatable in opposing directions to produce flows of pressurized fluid in two directions. Each pump **68A-68D** may be fluidly connected to a back flow preventor valve **78** that is configured to prevent back flow of pressurized fluid into the respective pump **68A-68D**. Alternatively, one or more of pumps **68A-68D** and corresponding back flow preventor valve **78** may be replaced by a pump configured to produce only a unidirectional flow of pressurized fluid and a check valve for preventing back flow of pressurized fluid into the pumps **68A-68D**. Also, back flow preventor valve **78** may be an electro-hydraulic valve (as shown in FIG. 2), a hydro-mechanical valve (e.g., controlled by the controller controlling displacement of pumps **68A-68D**), etc.

One or more pumps **68A-68D** may also be selectively operated as a motor. More specifically, when an associated actuator is operating in an overrunning condition (e.g., a condition in which the load drives the actuator), the fluid discharged from the actuator may have a pressure elevated higher than an output pressure of the corresponding pump(s) **68A-68D**. In this situation, the elevated pressure of the actuator fluid directed back through the corresponding pump(s) **68A-68D** may function to drive the corresponding pump(s) **68A-68D** to rotate with or without assistance from power source **18**. Under some circumstances, one or more pumps **68A-68D** may even be capable of imparting energy to power source **18**, thereby improving an efficiency and/or capacity of power source **18**.

It may be desirable to fluidly connect an actuator to more than one of pumps **68A-68D** simultaneously. For this purpose, a combiner valve arrangement **80** may fluidly connect two or more meterless circuits **58**, **60**, **62**, **64**. For example, in the disclosed embodiment, one combiner valve arrangement **80** is configured to fluidly connect meterless circuits **58**, **60**, and another combiner valve arrangement **80** is configured to

fluidly connect meterless circuits **62**, **64**. The following discussion relates to combiner valve arrangement **80** of meterless circuits **58**, **60**, but it is understood that the same description applies to combiner valve arrangement **80** of meterless circuits **62**, **64**.

By controlling combiner valve arrangement **80**, the actuators in meterless circuit **58** (e.g., hydraulic cylinder **32** and swing motor **43**) may be selectively connected only to pump **68A** in a closed loop manner, or to both pumps **68A** and **68B** in a closed loop manner. Also, the actuators in meterless circuit **60** (e.g., hydraulic cylinders **26**) may be selectively connected only to pump **68B** in a closed loop manner, or to both pumps **68A** and **68B** in a closed loop manner.

Combiner valve arrangement **80** may include up to four independent metering cartridge valves. For example, in the disclosed embodiment, each combiner valve arrangement **80** includes a first upper valve **80A**, a second upper valve **80B**, a first lower valve **80C**, and a second lower valve **80D**. Alternatively, each combiner valve arrangement **80** may be realized using other types of valves, such as spool valves, poppet valves, etc. Valves **80A-80D** may be on/off type valves, or proportional valves that are adjustable between full and partial flow-passing positions and a flow-blocking position. For example, valves **80A-80D** may be solenoid-actuated between full and partial flow-passing positions, and spring-biased to the flow-blocking position. First upper valve **80A** may be positioned between first pump passages **70** of first and second meterless circuits **58**, **60**. Second upper valve **80B** may be positioned between second pump passage **72** of second meterless circuit **60** and first pump passage **70** of first meterless circuit **58**. First lower valve **80C** may be positioned between first pump passage **70** of second meterless circuit **60** and second pump passage **72** of first meterless circuit **58**. Second lower valve **80D** may be positioned between second pump passages **72** of first and second meterless circuits **58**, **60**.

Valves **80A-80D** provide flow-combining functionality to allow each actuator of meterless circuits **58**, **60** to be fluidly connected in a closed loop manner to both pumps **68A** and **68B** simultaneously. When it is desired to provide pressurized fluid from both pumps **68A** and **68B** to the actuators, valves **80A-80D** are positioned depending on, for example, the direction of discharge of fluid from pumps **68A**, **68B** and/or the desired direction of movement of the actuators. For example, when first pump passages **70** of first and second meterless circuits **58**, **60** are pressurized by pumps **68A**, **68B**, first upper valve **80A** may be moved to its flow-passing position such that pressurized fluid from pumps **68A**, **68B** to respective first pump passages **70** of first and second meterless circuits **58**, **60** may combine and be supplied to the actuators via their associated switching valve, such as spool switching valve **82** or switching valve arrangements **84** (described below). At this same time, second lower valve **80D** may be in its flow-passing position so that flow discharged from the actuators, which passes through their associated spool switching valve **82** or switching valve arrangements **84**, may be directed to second pump passages **72** of first and second meterless circuits **58**, **60** and back to pumps **68A**, **68B**. In this configuration, swing motor **43** and hydraulic cylinders **26**, **32** are connected in a closed loop manner to pumps **68A** and **68B**.

Accordingly, valves **80A-80D** are configured to communicate a combined flow from pumps **68A** and **68B** to the actuators via spool switching valve **82** or switching valve arrangements **84**. As described below, spool switching valve **82** may be controlled to direct flow to one chamber of swing motor **43** and discharge flow from the other chamber to effect move-

ment of the pumping mechanism of swing motor **43**. Switching valve arrangements **84** may be controlled to direct flow to first or second chamber **52**, **54** of hydraulic cylinders **26**, **32** and discharge flow from the other one of first or second chamber **52**, **54** to effect retraction or extension of the hydraulic cylinders **26**, **32**. Thus, spool switching valve **82** and switching valve arrangements **84** may be controlled to determine which chambers of the actuators receive or discharge fluid and the rate at which fluid is received/discharged.

In certain situations, it may be desirable to direct substantially all flow from both pumps **68A** and **68B** to only one of the actuators in meterless circuits **58**, **60**. In those situations, spool switching valve **82** and/or switching valve arrangements **84** associated with the actuators may be controlled to block flow to the associated actuator. For example, if it is desirable to direct substantially all flow from both pumps **68A** and **68B** to hydraulic cylinders **26**, then spool switching valve **82** associated with swing motor **43** and valves **84A-84D** (described below) of switching valve arrangement **84** associated with hydraulic cylinder **32** may be moved to their respective flow-blocking positions. In this configuration, hydraulic cylinders **26** are the only actuators that are connected in a closed loop manner to pumps **68A** and **68B**. Alternatively, if it is desirable to direct substantially all flow from both pumps **68A** and **68B** to hydraulic cylinder **32**, then spool switching valve **82** associated with swing motor **43** and valves **84A-84D** of switching valve arrangement **84** associated with hydraulic cylinders **26** may be moved to their respective flow-blocking positions. In this configuration, hydraulic cylinder **32** is the only actuator that is connected in a closed loop manner to pumps **68A** and **68B**.

Valves **80A-80D** are positioned in their flow-blocking positions when it is desired to provide pressurized fluid from pump **68A** only to the actuators of first meterless circuit **58** (e.g., swing motor **43** and hydraulic cylinder **32**) and to provide pressurized fluid from pump **68B** only to the actuator of the second meterless circuit **60** (e.g., hydraulic cylinder **26**) without combining the flows. In this configuration, swing motor **43** and hydraulic cylinder **32** are connected in a closed loop manner only to pump **68A**, and hydraulic cylinders **26** is connected in a closed loop manner only to pump **68B**.

Combiner valve arrangement **80** of meterless circuits **62**, **64** may operate similarly to combiner valve arrangement **80** of meterless circuits **58**, **60**, as described above. Thus, combiner valve arrangement **80** of meterless circuits **62**, **64** may provide flow-combining functionality to allow the actuators of meterless circuits **62**, **64** to be fluidly connected in a closed loop manner to both pumps **68C** and **68D**. Combiner valve arrangement **80** of meterless circuits **62**, **64** may also allow the actuator of meterless circuit **62** (e.g., hydraulic cylinder **34**) to be fluidly connected in a closed loop manner only to pump **68C**, and to allow the actuators of meterless circuit **64** (e.g., left and right travel motors **42L**, **42R**) to be fluidly connected in a closed loop manner only to pump **68D**.

As described above, a switching valve, such as spool switching valve **82** or switching valve arrangement **84**, may be fluidly connected to each actuator to control or meter flow to and from the chambers of each actuator. For example, spool switching valve **82** associated with swing motor **43** may meter flow to and from the chambers of swing motor **43**, and switching valve arrangement **84** associated with hydraulic cylinder **32** may meter flow to and from first and second chambers **52**, **54**. As a result, spool switching valves **82** and switching valve arrangements **84** allow speed and/or directional adjustment of an actuator independently from other actuators, such as the actuators within the same closed loop. Other types of switching valves may be provided as known in

the art. Further, spool switching valve **82** and switching valve arrangement **84** may be substituted for each other. For example, switching valve arrangements **84** may be replaced by spool switching valves **82** in certain applications, or vice versa.

Spool switching valve **82** may be provided in meterless circuits **58**, **62**, **64** to provide flow-switching functionality and is fluidly connected to hydraulic cylinder **34**, left-travel motor **42L**, right travel motor **42R**, and swing motor **43**, respectively. Spool switching valve **82** may be positioned between first and second pump passages **70**, **72** to control the amount of fluid supplied to the actuator or discharged from the actuator. For example, swing motor **43** may include first and second actuator passages, and spool switching valve **82** may control the rate of flow through the actuator passages. In the disclosed embodiment, spool switching valves **82** may be on/off type valves, or proportional valves that are adjustable between full and partial flow-passing positions and a flow-blocking position. For example, the valves may be solenoid-actuated between full and partial flow-passing positions, and spring-biased to the flow-blocking position. When spool switching valves **82** are in the flow-blocking positions, fluid flowing within first and second pump passages **70**, **72** may not pass through and substantially affect the motion of the actuator.

Switching valve arrangement **84** may be provided in meterless circuits **58**, **60**, and fluidly connected to the associated linear actuators (e.g., hydraulic cylinders **26**, **32**). Switching valve arrangement **84** may include four valves, including a first rod-end valve **84A**, a second rod-end valve **84B**, a first head-end valve **84C**, and a second head-end valve **84D**. First rod-end valve **84A** may be positioned between first pump passage **70** and rod-end passage **74** in the respective meterless circuit **58**, **60**. Second rod-end valve **84B** may be positioned between second pump passage **72** and rod-end passage **74** in the respective meterless circuit **58**, **60**. First head-end valve **84C** may be positioned between first pump passage **70** and head-end passage **76** in the respective meterless circuit **58**, **60**. Second head-end valve **84D** may be positioned between second pump passage **72** and head-end passage **76** in the respective meterless circuit **58**, **60**. Like spool switching valves **82**, valves **84A-84D** may be on/off type valves, or proportional valves that are adjustable between full and partial flow-passing positions and a flow-blocking position. For example, valves **84A-84D** may be solenoid-actuated between full and partial flow-passing positions, and spring-biased to the flow-blocking position.

Valves **84A-84D** provide flow-switching functionality. For example, there may be times when movement of swing motor **43** in the first direction and retraction of hydraulic actuator **32** is desired, while at other times movement of swing motor **43** in the first direction and extension of hydraulic actuator **32** is desired. During the first situation, pump **68A** and/or pump **68B** may be required to pressurize first pump passage **70** in first meterless circuit **58** and rod-end passage **74**, while during the second situation, pump **68A** and/or pump **68B** may be required to pressurize first pump passage **70** in first meterless circuit **58** and head-end passage **76**. Valves **84A-84D** may facilitate these operations. For example, when first pump passage **70** in first meterless circuit **58** is pressurized by pump **68A** and/or pump **68B** and retraction of the hydraulic actuator **32** is desired, first rod-end valve **84A** may be moved to its flow-passing position such that rod-end passage **74** and second chamber **54** of hydraulic cylinder **32** are also pressurized. At this same time, second head-end valve **84D** may be in its flow-passing position such that fluid discharged from first chamber **52** passes through head-end passage **76** to second

pump passage **72** in first meterless circuit **58** and back to pump **68A**. If both pumps **68A**, **68B** are supplying fluid to hydraulic cylinder **32** via combiner valve arrangement **80**, then fluid discharged from first chamber **52** may also pass through head-end passage **76** to second pump passage **72** in second meterless circuit **60** and back to pump **68B**. In contrast, when first pump passage **70** in first meterless circuit **58** is pressurized by pump **68A** and/or pump **68B** and extension of hydraulic actuator **32** is desired, first head-end valve **84C** may be moved to its flow-passing position such that head-end passage **76** and first chamber **52** of hydraulic actuator **32** are also pressurized. At this same time, second rod-end valve **84B** may be in its flow-passing position such that fluid discharged from second chamber **54** passes through rod-end passage **74** to second pump passage **72** in first meterless circuit **58** and back to pump **68A**. If both pumps **68A**, **68B** are supplying fluid to hydraulic cylinder **32** via combiner valve arrangement **80**, then fluid discharged from second chamber **54** may also pass through head-end passage **76** to second pump passage **72** in second meterless circuit **60** and back to pump **68B**. Similar movements of valves **84A-84D** may be initiated to provide for movement of swing motor **43** in the second direction during extensions and retractions of hydraulic cylinder **32**. Also, switching valve arrangement **84** associated with hydraulic cylinders **26** may also be operated similarly to extend and retract hydraulic cylinders **26** when both pumps **68A**, **68B** are providing fluid to hydraulic cylinders **26**.

In some embodiments, switching valve arrangements **84** may be used to facilitate fluid regeneration within the associated linear actuator. For example, when valves **84B**, **84D** are moved to their flow passing positions and valves **84A**, **84C** are in their flow-blocking positions, high-pressure fluid may be transferred from one chamber to the other of the linear actuator via valves **84B**, **84D**, without the fluid ever passing through pumps **68A**, **68B**. This operation may help to reduce loads on pumps **68A**, **68B**, while still satisfying operator demands, thereby increasing an efficiency of machine **10**. Similar functionality may alternatively be achieved by moving valves **84A**, **84C** to their flow-passing positions while holding valves **84B**, **84D** in their flow-blocking positions.

Switching valves **84C**, **84D** may also function as load-holding valves, hydraulically locking movement of the actuator, when the actuator has a non-zero displacement and switching valves **84C**, **84D** are in their flow-blocking positions. Alternatively, or in addition, load holding valves **86** may be fluidly connected to hydraulic cylinders **26**, **32** to perform this function.

Check valves **92** may be provided to assist in regulating make up of fluid flow, e.g., supplied by or discharged from pumps **68A-68D** and/or the actuators (e.g., hydraulic cylinders **26**, **32**, **34**, swing motor **43**, left and right travel motors **42L**, **42R**, etc.).

It will be appreciated by those of skill in the art that the respective rates of hydraulic fluid flowing into and out of the actuators may not be equal. For example, the respective rates of hydraulic fluid flowing into and out of first and second chambers **52**, **54** of hydraulic cylinders **26**, **32**, **34** during extension and retraction may not be equal. Because of the location of the rod portion of piston assembly **50** within second chamber **54**, piston assembly **50** may have a reduced pressure area within second chamber **54**, as compared with a pressure area within first chamber **52**. Accordingly, during retraction of hydraulic cylinders **26**, **32**, **34**, more hydraulic fluid may be forced out of first chamber **52** than can be consumed by second chamber **54** and, during extension, more hydraulic fluid may be consumed by first chamber **52** than is forced out of second chamber **54**. In order to accommodate

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the excess fluid discharge during retraction and the additional fluid required during extension, each of meterless circuits 58, 60, 62 may be provided with two makeup valves 94 and two relief valves 96 that connect first and second pump passages 70, 72 to charge circuit 66 via a common passage 100. In addition, meterless circuit 64 may be provided with two check valves 92 and two relief valves 96 that connect first and second pump passages 70, 72 to charge circuit 66 via common passage 100.

Makeup valves 94 may each be a proportional valve that is disposed between common passage 100 and one of first and second pump passages 70, 72 and configured to selectively allow pressurized fluid from charge circuit 66 to enter first and second pump passages 70, 72. In particular, each of makeup valves 94 may be solenoid-actuated from a first position at which fluid freely flows between common passage 100 and the respective first and second pump passage 70, 72, toward a second position at which fluid from common passage 100 may flow only into first and second pump passage 70, 72 when a pressure of common passage 100 exceeds the pressure of first and second pump passages 70, 72 by a threshold amount. Makeup valves 94 may be spring-biased toward their second positions, and only moved toward their first positions during operations known to have need of positive or negative makeup fluid. Makeup valves 94 may also be used to facilitate fluid regeneration between first and second pump passages 70, 72 within a particular circuit, by simultaneously moving together at least partway to their first positions.

Relief valves 96 may be provided to allow fluid relief from each meterless circuit 58, 60, 62, 64 into charge circuit 66 when a pressure of the fluid exceeds a set threshold of relief valves 96. Relief valves 96 may be set to operate at relatively high pressure levels in order to prevent damage to hydraulic system 56, for example, at levels that may only be reached when hydraulic cylinders 26, 32, 34 reach an end-of-stroke position and the flow from associated pumps 68A-68D is nonzero, during a stall condition due to a large load, or during a failure condition of hydraulic system 56.

Charge circuit 66 may include at least one hydraulic source fluidly connected to common passage 100 described above. In the disclosed embodiment, charge circuit 66 has two sources, including a charge pump 102 and an accumulator 104, which may be fluidly connected to common passage 100 in parallel to provide makeup fluid to meterless circuits 58, 60, 62, 64. Charge pump 102 may embody, for example, an engine- or ground-driven, variable- or fixed-displacement pump configured to draw fluid from a tank 106, pressurize the fluid, and discharge the fluid into common passage 100. Accumulator 104 may embody, for example, a compressed gas, membrane/spring, or bladder type of accumulator configured to accumulate pressurized fluid from and discharge pressurized fluid into common passage 100. Excess hydraulic fluid, either from charge pump 102 or from meterless circuits 58, 60, 62, 64 (i.e., from operation of pumps 68A-68D and/or the rotary and linear actuators) may be directed into either accumulator 104 or into tank 106 by way of a charge relief valve 108 disposed in a return passage 110. Charge relief valve 108 may be movable from a flow-blocking position toward a flow-passing position as a result of elevated fluid pressures within common passage 100 and return passage 110. A manual service valve 112 may be associated with accumulator 104 to facilitate draining of accumulator 104 to tank 106 during service of charge circuit 66.

During operation of machine 10, the operator of machine 10 may utilize interface device 46 to provide a signal that identifies a desired movement of the various linear and/or rotary actuators to a controller (not shown). Based upon one

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or more signals, including the signal from interface device 46 and, for example, signals from various pressure and/or position sensors (not shown) located throughout hydraulic system 56, the controller may command movement of the different valves and/or displacement changes of the different pumps and motors to advance a particular one or more of the linear and/or rotary actuators to a desired position in a desired manner (i.e., at a desired speed and/or with a desired force).

The controller may embody a single microprocessor or multiple microprocessors that include components for controlling operations of hydraulic system 56 based on input from an operator of machine 10 and based on sensed or other known operational parameters. Numerous commercially available microprocessors can be configured to perform the functions of the controller. It should be appreciated that the controller could readily be embodied in a general machine microprocessor capable of controlling numerous machine functions. The controller may include a memory, a secondary storage device, a processor, and any other components for running an application. Various other circuits may be associated with the controller such as power supply circuitry, signal conditioning circuitry, solenoid driver circuitry, and other types of circuitry.

INDUSTRIAL APPLICABILITY

The disclosed hydraulic system may be applicable to any machine where improved hydraulic efficiency and performance is desired. The disclosed hydraulic system may provide for improved efficiency through the use of meterless technology. The disclosed hydraulic system may provide for enhanced functionality and control through the selective use of novel circuit configurations. Operation of hydraulic system 56 will now be described.

During operation of machine 10, an operator located within station 20 may command a particular motion of work tool 14 in a desired direction and at a desired velocity by way of interface device 46. One or more corresponding signals generated by interface device 46 may be provided to the controller indicative of the desired motion, along with machine performance information, for example sensor data such as pressure data, position data, speed data, pump displacement data, and other data known in the art.

In response to the signals from interface device 46 and based on the machine performance information, the controller may generate control signals directed to pumps 68A-68D, motors 43, 42L, 42R, and to valves 78, 80A-80D, 82, 84A-84D, 86, 94. For example, the operator may request via interface device 46 that hydraulic cylinder 32 be retracted. When this occurs, the controller may generate a control signal that causes pump 68A to increase its displacement and discharge fluid into first pump passage 70 of meterless circuit 58. In addition, the controller may generate a control signal that causes first rod-end valve 84A and second head-end valve 84D to move toward and/or remain in their flow-passing positions. At this time, second rod-end valve 84B and first head-end valve 84C may be in their flow-blocking positions. As fluid from pump 68A passes into second chamber 54 of hydraulic cylinder 32 via first pump and rod-end passages 70, 74, fluid may be discharged from first chamber 52 back to pump 68A via head-end and second pump passages 76, 72.

The motion of hydraulic cylinder 32 may be reversed in two different ways. First, the operation of pump 68A may be reversed, thereby reversing the flows of fluid into and out of hydraulic cylinder 32. Otherwise, the motion of hydraulic cylinder 32 may be reversed by switching the positions of first and second pump and rod- and head-end valves 84A-84D. If,

during the motion of hydraulic cylinder 32, the pressure of fluid within either of first or second pump passages 70, 72 becomes excessive (for example, during an overrunning condition), fluid may be relieved from the pressurized passage to tank 106 via relief valves 96 and common passage 100. In contrast, when the fluid pressure becomes too low, fluid from charge circuit 66 may be allowed into meterless circuit 58 via common passage 100 and makeup valves 94.

During motion of hydraulic cylinder 32, the operator may simultaneously request movement of swing motor 43. For example, to rotate swing motor 43 in the first direction, the controller may generate a control signal that increases the displacement of swing motor 43. In addition, the controller may generate a control signal that causes switching valve 82 to move toward and/or remain in its flow-passing position. After fluid from pump 68A passes into and through swing motor 43 via first pump passage 70, the fluid may return to pump 68A via second pump passage 72. To reverse the motion of swing motor 43, spool switching valve 82 may adjust the direction of flow of pressurized fluid to the swing motor 43 or the output direction of pump 68A may be reversed. Also, displacement of swing motor 43 may be controlled to adjust the torque output of swing motor 43. If, during the motion of swing motor 43, the pressure of fluid within either of first or second pump passages 70, 72 becomes excessive (for example during an overrunning condition), fluid may be relieved from the pressurized passage to tank 106 via relief valves 96 and common passage 100.

During the operations described above, valves 80A-80D may be in their flow-blocking positions so that swing motor 43 and hydraulic cylinder 32 only communicate fluid in a closed loop manner with pump 68A, and hydraulic cylinders 26 only communicate fluid in a closed loop manner with pump 68B. Alternatively, each actuator (e.g., hydraulic cylinders 26, 32, 34, swing motor 43, and left and right travel motors 42L, 42R) may receive flow from one or two of pumps 68A-68D. In the disclosed embodiment, by controlling valves 80A-80D, 82, 84A-84D in meterless circuits 58, 60, each of hydraulic cylinder 32 and swing motor 43 may be selectively connected only to pump 68A in a closed loop manner or to both pumps 68A and 68B, and hydraulic cylinders 26 may be selectively connected only to pump 68B in a closed loop manner or to both pumps 68A and 68B in a closed loop manner. Similarly, by controlling valves 80A-80D, 82, 84A-84D in meterless circuits 62, 64, hydraulic cylinder 34 may be selectively connected only to pump 68C in a closed loop manner, or to both pumps 68C and 68D in a closed loop manner, and each of right travel motor 42R and left travel motor 42L may be selectively connected only to pump 68D in a closed loop manner, or to both pumps 68C and 68D in a closed loop manner.

In certain operations, it may be desirable to increase the amount of fluid communicated to the actuator(s), e.g., so that the actuator(s) may move faster, by providing fluid from more than one of pumps 68A-68D to the actuator(s). Thus, combined flow from two pumps may be provided to each actuator if an increase in speed of the actuator is desired within the power capabilities of the engine.

Combining flow from two pumps to supply to one or more actuators may also assist in ensuring that the actuators operate as desired. Each of pumps 68A-68D has a certain flow rate limit dictated by its respective maximum displacement. Certain actuators, however, may require a flow rate greater than the maximum flow provided by a single pump in order to function as desired (e.g., to fulfill cycle requirements, such as cycle timing, etc.). For example, hydraulic cylinder 32 (associated with stick 28) and hydraulic cylinders 26 (associated

with boom 22) may each require flow from more than one pump in order to meet single-function performance requirements. Thus, if operation of a particular actuator is initiated and it is determined that more than one of pumps 68A-68D are needed to provide the desired flow rate to a particular actuator, then the controller may generate a control signal that causes valves 80A-80D, 82, 84A-84D to communicate a combined flow from two of pumps 68A-68D to the actuator to be operated. For example, if hydraulic cylinders 26 are moving and hydraulic cylinder 32 and swing motor 43 are not moving (and therefore do not require flow), and it is desired to increase the flow rate to hydraulic cylinders 26 so that the hydraulic cylinders 26 receive a combined flow from pumps 68A and 68B, the controller may generate a control signal that causes valves 80A-80D in meterless circuits 58, 60 to communicate flow from both pumps 68A and 68B to hydraulic cylinders 26. At the same time, switching valve arrangement 84 associated with hydraulic cylinder 32 and spool switching valve 82 associated with swing motor 43 may be moved to their flow-blocking positions. As a result, hydraulic cylinders 26 may receive sufficient flow to operate as desired due to the combined flow from both pumps 68A and 68B.

In certain situations, multiple actuators may be operated simultaneously, but the desired flow rate to the operating actuators (the commanded amount) may exceed the flow rate that the pumps are capable of supplying to those actuators. In such situations, the controller may prioritize one or more actuators so that the desired flow rate is supplied to the actuators having higher priority. For example, in certain embodiments, hydraulic cylinders 26 associated with boom 22 may have the highest priority so that if the operator is moving swing motor 43 and hydraulic cylinders 32, 26 simultaneously, the controller may ensure that hydraulic cylinders 26 receive a flow rate at a predetermined value, which may cause less flow to be directed to swing motor 43 and hydraulic cylinder 32. As another alternative, the controller may scale down the commanded rates of flow to all of the actuators being operated.

Further, in certain situations, since different actuators may operate simultaneously and require a different rate/pressure of flow to function as desired, valves 80A-80D, 82, 84A-84D may be controlled to maintain a pressure difference between meterless circuits and/or between different actuators. For example, when a combined flow from pumps 68A and 68B is communicated in a closed loop manner to hydraulic cylinders 26 and hydraulic cylinder 32, it may be desired to supply flow at a higher pressure to hydraulic cylinders 26 than hydraulic cylinder 32. Thus, the controller may generate a control signal that causes valves 80A-80D to maintain a pressure difference so that flow in meterless circuit 60 that is communicated to hydraulic cylinders 26 is at a higher pressure than flow in meterless circuit 58 that is communicated to hydraulic cylinder 32. Alternatively, or in addition, the controller may generate a control signal that causes the switching valves 84A-84D associated with respective hydraulic cylinders 26 and/or hydraulic cylinder 32 to maintain the pressure difference.

As described above, displacement control of pumps 68A-68D may depend on the desired operation of the rotary and linear actuators. When both rotary and linear actuator motion is simultaneously desired within a single circuit, however, directional displacement control of the associated pump may be driven based solely on the desired motion of the linear actuator(s) (although the displacement magnitude of pump may be based on flow requirements of both the rotary and linear actuators). Direction or speed of the linear actuator(s) may be adjusted independently from each other and the rotary actuators. In the disclosed embodiment, speed of the linear

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actuator(s) may be adjusted by displacement of the associated pump(s), and switching valves **82**, **84** may be controlled so that a reversal of the associated linear actuator(s) does not affect other actuators. In other words, switching valves **82**, **84** may switch the direction of flow. For example, pump **68A** may pressurize first pump passage **70** in meterless circuit **58** in order to effect extension of hydraulic cylinder **32** and to rotate swing motor **43** clockwise. If retraction of hydraulic cylinder **32** is desired while maintaining the clockwise rotation of swing motor **43**, then switching valve arrangement **84** associated with hydraulic cylinder **32** may switch the direction of flow to hydraulic cylinder **32** to effect retraction without having to adjust the direction of flow from pump **68A**, which would affect the direction of rotation of swing motor **43**. In order to cause the rotary actuator(s) to move in a desired direction at a desired speed and/or with a desired torque, the displacement of the rotary actuator(s) may be selectively varied. Switching valves **82** associated with the rotary actuator(s) may be actuated to control the direction of the rotary actuator(s).

Also, as described above, the positioning of valves **80A-80D** and **84A-84D** may depend on the desired operation of the rotary and linear actuators. As a result, hydraulic system **56** may supplement flow to one or more actuators using more than one of pumps **68A-68D**. For example, if the operator does not desire to move hydraulic cylinders **26**, pump **68B** may be run to supplement the flow from pump **68A** to move swing motor **43** and/or hydraulic cylinder **32**.

When two or more of the linear and/or rotary actuators receive flow from one or two of pumps **68A-68D**, then displacement control of the pump(s) may be determined based on the meterless circuit receiving flow from the pump(s) having the higher load (pressure). For example, when a combined flow from pumps **68A** and **68B** is communicated in a closed loop manner to hydraulic cylinder **32** and swing motor **43**, it may be desired to supply flow at a higher pressure to hydraulic cylinder **32** than swing motor **43**. Thus, directional displacement of pumps **68A** and **68B** may be controlled to ensure that the higher pressure for hydraulic cylinder **32** is supplied. Displacement of swing motor **43** may be adjusted to meet its torque demand. As another example, when a combined flow from pumps **68A** and **68B** is communicated in a closed loop manner to hydraulic cylinder **32** and swing motor **43**, it may be desired to supply flow at a higher pressure to swing motor **43** than hydraulic cylinder **32**. Thus, directional displacement of pumps **68A** and **68B** may be controlled to ensure that the higher pressure for swing motor **43** is supplied. Flow to hydraulic cylinder **32** may be controlled by throttling flow to hydraulic cylinder **32** via switching valve arrangement **84**.

Regeneration of fluid may be possible during retracting and/or extending operations of the linear actuators, such as hydraulic cylinder(s) **26**, **32**, **34**, when the pressure of fluid exiting the hydraulic cylinder is higher than the pressure of fluid entering the hydraulic cylinder (e.g., when the pressure in first chamber **52** is higher than the pressure in second chamber **54** of hydraulic cylinder(s) **26**, **32**, **34** for the case of an overrunning retraction operation of the hydraulic cylinder). Specifically, during the retracting operation described above, both of makeup valves **94** for the respective hydraulic cylinder(s) **26**, **32**, **34** may be simultaneously moved toward their flow-passing positions. In this configuration, makeup valves **94** may allow some of the fluid exiting first chamber **52** to bypass pump(s) **68A-68D** and flow directly into second chamber **54**. During the extending operation, both makeup valves **94** may allow some of the fluid exiting second chamber **54** to bypass pump(s) **68A-68D** and flow directly into first

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chamber **52**. These operations may help to reduce a load on pumps **68A-68D**, while still satisfying operator demands, thereby increasing an efficiency of machine **10**. In some embodiments, makeup valves **94** may be held partially closed during regeneration to facilitate some energy dissipation that improves controllability.

Makeup valves **94** may also be used to allow flow to bypass pumps **68A-68D** so that an operator of machine **10** may experience an "open-center" feel associated with control of the associated hydraulic cylinder(s) **26**, **32**, **34**. For example, makeup valves **94** may be controlled to bypass flow when the load increases up to the point of stopping motion of the actuator, e.g., determined based on a monitored or sensed flow pressure. The "open-center" feel may provide the operator with a feel for the load on the hydraulic cylinder(s) **26**, **32**, **34**.

In the disclosed embodiments of hydraulic system **56**, flows provided by pumps **68A-68D** may be substantially unrestricted such that significant energy is not unnecessarily wasted in the actuation process. Thus, embodiments of the disclosure may provide improved energy usage and conservation. In addition, the meterless operation of hydraulic system **56** may, in some applications, allow for a reduction or even complete elimination of metering valves for controlling fluid flow associated with the linear and rotary actuators. This reduction may result in a less complicated and/or less expensive system.

The disclosed hydraulic system may also provide for enhanced pump overspeed protection. In particular, during overrunning retracting or extending operations of hydraulic cylinders **26**, **32**, **34**, when fluid exiting first chambers **52** (or second chambers **54**) has elevated pressures, the highly-pressurized fluid may be rerouted back into second chambers **54** (or first chambers **52**) via makeup valves **94**, without the fluid ever passing through pumps **68A-68D**. Not only does the rerouting help to improve machine efficiencies, but the bypassing of pumps **68A-68D** may also reduce a likelihood of pumps **68A-68D** overspeeding.

It will be apparent to those skilled in the art that various modifications and variations can be made to the disclosed hydraulic system. Other embodiments will be apparent to those skilled in the art from consideration of the specification and practice of the disclosed hydraulic system. It is intended that the specification and examples be considered as exemplary only, with a true scope being indicated by the following claims and their equivalents.

What is claimed is:

1. A hydraulic system comprising:

a variable-displacement first pump;

a variable-displacement second pump;

a first actuator selectively connected either to the first pump in a closed loop manner and not the second pump, or to the first and second pumps in a closed loop manner;

a second actuator selectively connected either to the second pump in a closed loop manner and not the first pump, or to the first and second pumps in a closed loop manner; and

a variable-displacement rotary actuator selectively connected either to the first pump in a closed loop manner and not the second pump, or to the first and second pumps in a closed loop manner.

2. The hydraulic system of claim 1, wherein the first and second pumps are over-center pumps.

3. The hydraulic system of claim 1, wherein the first actuator is a linear actuator.

4. The hydraulic system of claim 1, wherein the first actuator is a second rotary actuator.

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5. The hydraulic system of claim 1, further comprising:
at least one switching valve fluidly connected to at least one
of the first actuator, the second actuator, or the rotary
actuator;
wherein the at least one switching valve is configured to
control an amount of fluid through a first actuator pas-
sage and a second actuator passage connected to the at
least one of the first actuator, the second actuator, or the
rotary actuator.
6. The hydraulic system of claim 5, wherein the at least one
switching valve includes a spool switching valve configured
to control the amount of fluid passing through the first actua-
tor passage and the second actuator passage connected to the
rotary actuator.
7. The hydraulic system of claim 5, wherein the at least one
switching valve includes four independent metering valves
configured to control the amount of fluid passing through the
first actuator passage and the second actuator passage con-
nected to at least one of the first actuator or the second actua-
tor.
8. The hydraulic system of claim 1, wherein the first and
second actuators are linear actuators, the hydraulic system
further comprising:
at least one variable-displacement first switching valve
connected to the first actuator and configured to allow
fluid to be transferred between first and second cham-
bers of the first actuator to facilitate fluid regeneration
within the first actuator; and
at least one variable-displacement second switching valve
connected to the second actuator and configured to allow
fluid to be transferred between first and second cham-
bers of the second actuator to facilitate fluid regeneration
within the second actuator.
9. The hydraulic system of claim 1, wherein the first and
second actuators are linear actuators, the hydraulic system
further comprising:
at least one first switching valve fluidly connected to the
first actuator; and
at least one second switching valve fluidly connected to the
second actuator;
wherein, when the first and second pumps are simulta-
neously connected to at least one of the first and second
actuators in a closed-loop manner, the at least one first
switching valve is configured to meter flow to the first
actuator and the at least one second switching valve is
configured to meter flow to the second actuator to adjust
directions of flow of the first and second actuators inde-
pendently.
10. The hydraulic system of claim 9, wherein displacement
of the rotary actuator is adjustable to control torque output of
the rotary actuator while the directions of flow of the first and
second actuators are independently adjustable via the at least
one first switching valve and the at least one second switching
valve.
11. The hydraulic system of claim 1, wherein the first
actuator, the second actuator, and the rotary actuator are con-
figured to simultaneously receive fluid from at least one of the
first pump or the second pump so that the first actuator, the
second actuator, and the rotary actuator move simultaneously.
12. The hydraulic system of claim 11, wherein, when the
first actuator, the second actuator, and the rotary actuator
simultaneously receive fluid from at least one of the first
pump or the second pump, at least one of the first actuator, the
second actuator, and the rotary actuator is configured to be
connected in a closed loop manner to the first pump and the
second pump.

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13. The hydraulic system of claim 1, further comprising a
combiner valve arrangement controllable to:
selectively connect the first actuator and the rotary actuator
either to the first pump in a closed loop manner and not
the second pump, or to the first and second pumps in a
closed loop manner; and
selectively connect the second actuator either to the second
pump in a closed loop manner and not the second pump,
or to the first and second pumps in a closed loop manner.
14. The hydraulic system of claim 13, wherein the com-
biner valve arrangement includes four independent metering
valves fluidly connected to the first pump, the second pump,
the first actuator, the second actuator, and the rotary actuator.
15. The hydraulic system of claim 1, wherein:
the hydraulic system is provided in a machine including a
body and an implement system; and
the first actuator is a hydraulic cylinder configured to move
at least one of a stick of the implement system or a work
tool of the machine;
the second actuator is a hydraulic cylinder configured to
move a boom of the implement system; and
the rotary actuator is a swing motor configured to move the
body.
16. The hydraulic system of claim 1, wherein:
the hydraulic system is provided in a machine including a
drive system, the drive system including left traction
device driven by a left travel motor and a right traction
device driven by a right travel motor;
the first actuator is one of the left and right travel motors;
and
the rotary actuator is the other one of the left and right travel
motors.
17. The hydraulic system of claim 16, wherein the second
actuator is a hydraulic cylinder configured to move the at least
one of a stick of the implement system or a work tool of the
machine.
18. A hydraulic system comprising:
a variable-displacement first pump;
a variable-displacement second pump;
a first actuator connected to the first pump in a closed loop
manner;
a second actuator selectively connected to the second pump
in a closed loop manner;
a variable-displacement rotary actuator selectively con-
nected to the first pump in a closed loop manner;
a combiner valve arrangement configured to:
selectively connect and disconnect the second pump
from the first actuator and the rotary actuator, and
selectively connect and disconnect the first pump from
the second actuator; and
at least one switching valve fluidly connected to at least one
of the first actuator, the second actuator, or the rotary
actuator, the at least one switching valve being config-
ured to control an amount of fluid passing through a first
actuator passage and a second actuator passage con-
nected to the at least one of the first actuator, the second
actuator, or the rotary actuator.
19. A method of operating a hydraulic system, the method
comprising:
pressurizing fluid with a first variable-displacement pump;
pressurizing fluid with a second variable-displacement
pump, the first and second pumps being capable of
simultaneously supplying pressurized fluid to at least
three actuators, the at least three actuators including a
variable-displacement rotary actuator, a linear actuator,
and a third actuator;

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selectively controlling whether to direct fluid pressurized
 by the first pump and the second pump to only one of the
 at least three actuators, to only two of the at least three
 actuators simultaneously, or to three of the at least three
 actuators simultaneously; 5
 returning the pressurized fluid to the first and second
 pumps in a closed-loop manner;
 adjusting displacement of the rotary actuator to control
 torque output of the rotary actuator; and
 metering the flow passing between the first and second 10
 pumps and the linear actuator to control movement of
 the linear actuator.

20. The method of claim **19**, wherein the first and second
 pumps are capable of simultaneously supplying pressurized
 fluid to the rotary actuator, the linear actuator, the third actua- 15
 tor, and a fourth actuator; and the method further comprises:
 selectively controlling whether to direct fluid pressurized
 by the first pump and the second pump to only one of the
 four actuators, to only two of the four actuators simul-
 taneously, to only three of the four actuators simulta- 20
 neously, or to all four of the actuators simultaneously.

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